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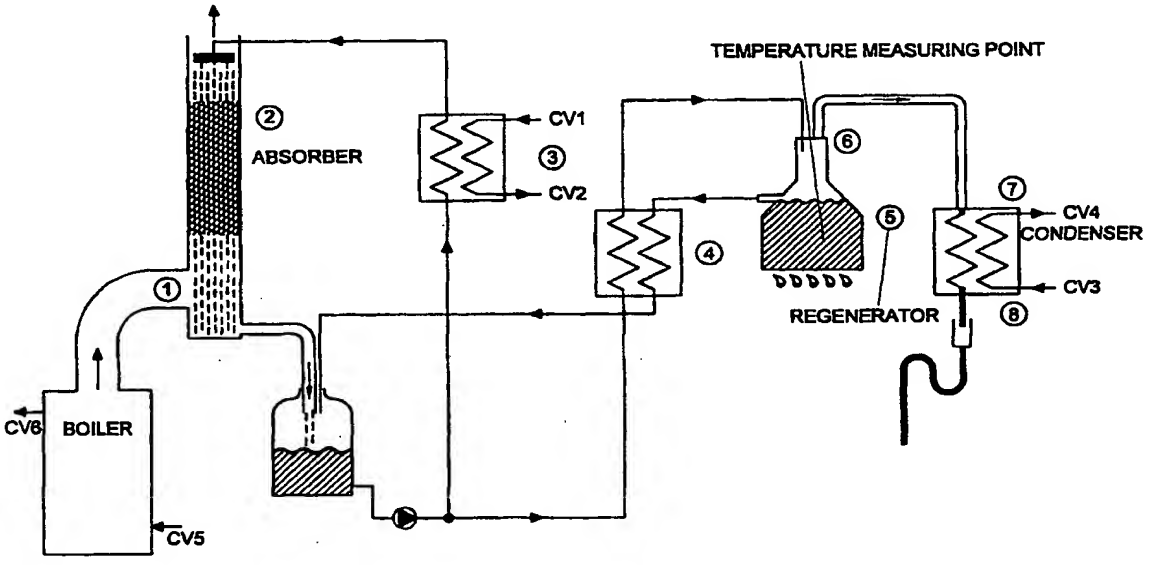
(54) Title: METHOD FOR TREATING A MOIST GAS STREAM



(57) Abstract

Method, and apparatus, for treating a moist gas stream and improving the efficiency of combustion plants and air conditioning plants, comprising: in an absorption plant (2), loading a recirculating sorbent with moisture from the moist gas stream; absorbing heat from the recirculating sorbent in a first heat exchanger (3), which is connected in a cycle with the absorption plant (2); supplying a part of the moisture–loaded sorbent to a regeneration plant (5) for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam; recycling the regenerated sorbent to the absorption plant (2); while the steam can be utilized for recovering water and the recovered water or steam can be used in fuel–reforming processes for a fuel cell.

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Title: Method for treating a moist gas stream

This invention relates to a method for treating a moist gas stream, and to an apparatus therefor. The invention further relates to a method for improving the efficiency of a heating boiler, an air conditioning plant, and a central heating system. The invention also relates to a method for recovering water from the exhaust gases of a fuel cell, and to an apparatus for recovering water from the exhaust gases of a fuel cell and the use of the water obtained according to the method in a fuel reforming process.

Much research has been conducted on the improvement of the efficiency of heating boilers. In the so-called high-efficiency CH-boiler, heat is recovered from the flue gases by means of a condensing device. High-efficiency central heating boilers (HE-CH) are based on a heat exchanger arranged in the egressive stream of combustion gases (flue gases) of the heating boiler, the incoming cooled water being preheated by heat exchange with the egressive stream of combustion gases.

Although with such HE-CH systems considerable improvements have been achieved over conventional boilers, the energy gain remains limited to the temperature difference between the egressive gas stream and the incoming water. The egressive stream of combustion gases of a heating system, however, also contains moisture in the form of water vapor. Water has a high heat of condensation. Due to this heat of condensation, a relatively small amount of water yields a proportionally large quantity of heat. A disadvantage of such condensing methods is also that only at lower temperatures water, and hence heat of condensation, can be extracted from the combustion gases.

The inventors have now made it their aim, in general, to utilize the heat present in the moist gas stream to improve the efficiency of such systems.

It has now been found that by the use of a method that extracts water from waste gases by means of a sorbent, a higher efficiency can be obtained.

Accordingly, it is an object of the invention to utilize the heat content of the moisture in a moist gas stream. It is also an object of the invention to arrive at an apparatus for recovering heat from a moist gas stream. Other objects of the invention are to improve the efficiency of a heating system and an air conditioning plant, and a method for heating a space. A further object of the invention is to reduce the emission of undesirable gases such as CO_2 and NO_x by a reduced use of fuels, and to reduce the amount of emitted water vapor, which may be visible in the form of condensation plumes.

Further objects and advantages of the invention will become apparent from the following description.

The invention relates to a method for treating a moist gas stream, wherein:

- in an absorption plant, a recirculating sorbent is loaded with moisture from the moist gas stream;
- in a first heat exchanger, which is connected in a cycle with the absorption plant, heat is absorbed from the recirculating sorbent;
- a part of the moisture-loaded sorbent is supplied to a regeneration plant for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam;
- the regenerated sorbent is recycled to the absorption plant.

Means for drying a humid air stream are further known from U.S. Patent 5,097,668, where use is made of water absorption by means of a sorbent. This technique is utilized in the cooling technique in air cooling and air conditioning plants for drying the incoming air.

A further aspect of the invention concerns a method for improving the efficiency of a heating boiler, wherein:

- in an absorption plant, a recirculating sorbent is loaded with moisture from flue gases of the heating boiler;

- in a first heat exchanger, which is connected in a cycle with the absorption plant, heat is absorbed from the recirculating sorbent;
- a part of the moisture-loaded sorbent is supplied to a regeneration plant for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam;
- the regenerated sorbent is recycled to the absorption plant; and
- the steam obtained is used for heating, recovering mechanical energy and/or recovering electric energy.

The invention further comprises a method for improving the efficiency of an air conditioning plant, wherein:

- in an absorption plant, a recirculating sorbent is loaded with moisture from the egressive gas stream of the air conditioning plant;
- in a first heat exchanger, which is connected in a cycle with the absorption plant, heat is absorbed from the recirculating sorbent;
- a part of the moisture-loaded sorbent is supplied to a regeneration plant for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam;
- the regenerated sorbent is recycled to the absorption plant; and
- the steam obtained is used for heating, recovering mechanical energy and/or recovering electric energy.

An air conditioning plant can be understood to mean a so-called air conditioner, which produces a humid gas stream. In fact, any plant that transports moist air can be used in the present invention. Thus, a fan transporting a humid gas stream can also be seen as an air conditioning plant in the light of the invention. It is also possible for a fan to be connected directly to a plant, thereby making it possible, in a space with humid air, to dry the space and to recover heat as well. This can be useful, for instance, in greenhouses. If CO_2 is supplied to a greenhouse (CO_2 fertilization) by firing the gas plant,

this results in an increased moisture content. To lower the moisture content, ventilation is carried out, whereby, however, not only the moisture is driven out but so is the additionally supplied CO_2. By installing an air conditioning plant as described above, the moisture is removed from the air while the CO_2 content remains unchanged.

In a further aspect, the invention comprises a method for heating a space utilizing a central heating system, comprising a heating boiler, and means for releasing heat to the surroundings, which method comprises:

- in an absorption plant, loading a recirculating sorbent with moisture from flue gases of the heating boiler;
- absorbing heat from the recirculating sorbent in a first heat exchanger which is connected in a cycle with the absorption plant;
- supplying a part of the moisture-loaded sorbent to a regeneration plant for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam;
- recycling the regenerated sorbent to the absorption plant; and
- using the steam obtained for heating, recovering mechanical energy and/or recovering electric energy.

In a preferred embodiment of the present invention, in a heating system, preferably a sorbent in solid form is used, or a mixture of a solid and a liquid sorbent.

As plants that are suitable for use in the present invention, any plant can be used that emits a moist gas stream, such as, for instance, a combined heat and power station, a heat pump, an internal combustion engine, a hot-water system, and the like. In general, this involves plants in which hydrocarbons are combusted, thereby releasing heat and forming flue gases. Hydrogen can also be used as fuel, as, for instance, in a fuel cell, whereby substantially water vapor is released.

The invention further comprises an apparatus for recovering heat from a moist gas stream, which comprises:

- at least one absorption plant with an inlet and an outlet for the gas stream, means for contacting a liquid sorbent for water with the gas stream, means for discharging the water-loaded sorbent, and means for recirculating the sorbent over the absorption plant;
- a first heat exchanger in combination with said means for recirculating the sorbent;
- a regeneration plant for the sorbent, connected in a cycle with the absorption plant;
- a means for recovering heat and/or mechanical or electric energy connected with the regeneration plant.

The inlet of the absorption plant can be connected with the outlet of a preceding combustion plant, such as the heating boiler of a central heating system, or with the outlet of an air conditioning plant. The inlet of the absorption plant can also be connected with a transport means for air, such as, for instance, a fan. For treating a humid gas stream from an air conditioning plant, in a preferred embodiment of the present invention, a sorbent can be used which may be in a solid or a liquid form or a combination thereof.

The hot moist gas stream entering the absorption plant may contain contaminants, in addition to the conventional combustion gases such as CO_2 and H_20. Many of these contaminants will not directly have an adverse effect on the invention, but there are contaminants which may have rather disastrous consequences in the longer term. An example thereof are acid contaminations such as, for instance, SO_2 and NO_x. But also basic and other contaminants can influence the functioning of the plant. The acid contaminations can originate, for instance, from the combustion processes of fossil fuels or from the air which has been used in the combustion. Some of these contaminants will be absorbed by the absorbent. Since in a preferred embodiment the absorbent is thermally regenerated (by distilling off water), there will arise an accumulation of these compounds and their reaction products in the

absorbent. Thus, SO_2 will be converted in the absorbent into sulfuric acid. This eventually leads to an unacceptable acidification of the absorbent. Tests have shown that at an SO_2 content of 2 ppm in the flue gas of the test plant, there occurred an acidification of the absorbent to a pH of -2 over the period of a year. In the method and apparatus according to the invention, to prevent this acidification, steps and means can be included that prevent this acidification and prevent the acid contaminants. Thus, for instance, acid filters can be installed, which can capture the acid compounds from the flue gases. It is also possible to use a strongly basic and hygroscopic absorbent, or to add neutralizing compounds to the absorbent, or compositions that can work as a buffer. It is also possible to capture the acid components with, for instance, a NEUTRABOX®, which is a known commercial de-acidification system for flue gas plants. The use of an electrochemical filter or a galvanic protection of the plant is also a suitable possibility of capturing the acid components.

Therefore, in a preferred embodiment of the method, the noxious components in the flue gases are captured or neutralized. To that end, in a preferred embodiment of the apparatus, means are included which provide for the capture or neutralization of the noxious components.

In a preferred embodiment of the present invention, regeneration of the sorbent occurs at a temperature in the range of 25 and 500°C, preferably in the range of 50 and 400°C, more preferably between 100 and 200°C. In the regenerator, the sorbent, preferably a hygroscopic liquid, is regenerated by heating. According as the hygroscopic liquid is more concentrated, the required regeneration temperature (the boiling point) will be higher. By controlling the temperature with a temperature control unit suitable therefor, the concentration of the hygroscopic

solution can be held at the desired value on the basis of the temperature.

In a preferred embodiment of the present invention, the heat of the combustion gases that are released upon heating of the regenerator can also be used for recovering heat, which may or may not be done by recycling these combustion gases into the absorption plant.

In a further form of the apparatus, different parts of the absorption plant and/or the regeneration plant and/or the heat exchangers and/or the buffer vessel and/or the pump can be integrated with the preceding plant to further increase practical efficiency and to further improve energetic efficiency. It is also possible to use a modular system. A fully integrated absorption and regeneration plant can be used as a module, which can subsequently be linked to any plant that emits a moist gas stream. Also, the module may be linked with a space from which a moist gas stream is supplied to the installation by a natural draft. Thus it is possible to obtain a considerable improvement of the efficiency in existing installations. The various, optionally integrated installation parts or modules may also be individually made of energy-saving design, or further contribute to increasing the efficiency of the plant by means of compaction and insulation of the plant.

A further advantage of the invention is that through an increased efficiency of the utilization of fossil fuels, the emission of undesirable gases such as CO_2, NO_x is reduced. Also the emission of water vapor is reduced to a considerable extent. These limitations of the emission underline the environment-friendliness of the present invention.

The water obtained by the regeneration of the sorbent is distilled water of a high grade. This water can be used for a multiplicity of possibilities, such as, for instance, boiler supply water. One of those possibilities of use is in fuel reforming processes in a fuel cell. In

these fuel reforming processes, natural gas is converted with the aid of steam into *inter alia* hydrogen (H_2) for the fuel cell. The required steam can be generated with the grade of water such as it is obtained in the method according to the invention from, for instance, the moist exhaust gases of a fuel cell. This creates the possibility, in accordance with the invention, of using a moist gas stream coming from a fuel cell for recovering water. This water, obtained with a method according to the invention, is subsequently used in a fuel reforming process, whereby fuel for a fuel cell is generated.

Thus, in a preferred embodiment of the invention, the water obtained by carrying out the method is used in fuel reforming processes.

In a preferred embodiment of the present invention, a heat exchange step is included between the supply of the sorbent to the regeneration step and the recycling of the regenerated sorbent to the absorption plant.

In the present invention, a sorbent is used. A sorbent for use in the present invention can be *inter alia* a solid desiccant, such as calcium hydride, magnesium perchlorate, aluminum oxide, silica, zeolites, molecular sieves or a synthetic drying agent such as polymers and the like.

Such a sorbent can, for instance in finely divided form, be contacted with the moist gas stream and in this way be loaded with water. In an optionally separate regeneration step, the solid sorbent is then regenerated and the water is released in the form of steam or energy. A further possibility is to apply the solid sorbent to a support. By subsequently providing several absorption units each containing an amount of solid sorbent, which may or may not be provided on a support material or support structure, units which have been loaded in an absorption step can subsequently be regenerated in a regeneration step

ıded unit has been brought into the

ɔ.

lid sorbent can also be used in the form of a porous solid material.

referred embodiment of the present invention, sorbent is used where the sorbent is based on ents, preferably an aqueous solution of esiccants, more preferably an aqueous solution logenides, such as lithium bromide.

hoice of the absorbents and the materials of such that the properties of the hygroscopic not have a negative influence on the plant, for ough corrosion or other chemical or physical

preferred embodiment of the present invention, ture of the gas stream supplied can be in a om 0 to 500 °C.

invention will now be further explained on the e appended figures and examples.

the drawings, Fig. 1 shows a schematic tion of an apparatus for carrying out a preferred of the method according to the invention.

moist gas stream is passed into the absorption an inlet (1). In the absorption plant (2), the comes into contact with a liquid sorbent which into the gas stream. The water-loaded sorbent is in a buffer vessel and, by means of a pump, cycled into the absorption plant along a heat (3). A part of the contents of the buffer vessel ferred by means of the pump to the regeneration , where the water-loaded sorbent is regenerated by. During this heating, steam is released, which is ugh a line (6) to a heat exchanger (7), whereafter lensed water is discharged through a condensate ge (8). The regenerated sorbent is recycled to the vessel, optionally along a heat exchanger (4)

included in the stream flowing in one direction and the other between the absorption and the regeneration plant.

In a preferred embodiment of the invention, the heat released in the heat exchangers can be used to heat the water of a heating system. In Fig. 1, these heat flows are indicated by CV1-CV6. Return water (CV1) from the heating cycle is initially preheated in heat exchanger (3). The water of higher temperature (CV2) is now led to heat exchanger (7), where the incoming water (CV3) is further heated. Thereafter, the water (CV4) can be passed to the heating boiler, where the incoming water (CV5) is further heated until the egressive stream of water (CV6) has reached a temperature level that is suitable for use in the heating system.

To improve the contact between the gas stream and the sorbent, contact improving means can be arranged in the absorption plant. In a preferred embodiment of the present invention, in the column of the absorption plant, contact improving means can be arranged to improve contact between the liquid sorbent and the combustion gases. Means suitable for this purpose are, for instance, tubes, rings, spheres, plates, Raschig rings, or the like.

Fig. 2 is a Mollier diagram showing that the egressive gas stream of a conventional heating plant under normal conditions has an enthalpy which is equal to the point indicated by (1) in the Mollier diagram.
The egressive gas stream of a high-efficiency CH has, depending on the temperature of the egressive gas stream, an enthalpy between the points 2 and 3. Although in this way already a considerable improvement of the efficiency has been obtained over the conventional boiler (80 to 200 kJ/kg), the egressive moist gas stream still contains a considerable amount of enthalpy. By making use of the invention as described in the claims, points 5 (starting from an efficiency of a high-efficiency CH indicated as point 2) and 4 (starting from an efficiency of a high-

efficiency CH indicated as point 3) can be achieved, which means an enthalpy gain of 160-240 kJ/kg.

Example

In a plant as described in Fig. 1, at different settings, a number of process quantities and efficiencies were determined. The table presents the values.

As hygroscopic liquid, an aqueous solution of about 50% by weight of lithium bromide was used.

The process was applied to gases from a commercially available gas-fired central heating boiler of 20 kW. The carbon dioxide content of the flue gases was 9%, which is a common composition for flue gases from such a plant.

The temperature of the return water (CV1) of the central heating system CH boiler was varied from 30 to 60°C. The temperature of the supply water (CV6) was 20°C higher.

The heat supply to the regenerator was controlled such that the temperature of the solution in the regenerator was 170 °C. As a result, the water content of the solution was as low as possible, and hence the hygroscopic action was as high as possible, without the risk of crystallization of the sorbent used in this experiment.

Under these conditions, the following were determined:

- the temperature of the sorbent flowing into the absorber
- the concentration of the sorbent in the absorber
- the temperature of the flue gases after the absorber
- the moisture content of the flue gases after the absorber

Based on the fuel/air ratio and the temperature and the moisture content of the flue gases, the flue gas side efficiency (based on the lower calorific value of natural gas) was determined.

For comparison, the values of a conventional condensing central heating boiler are also represented.

Carbon dioxide content	%	9	9	9	9
Temperature of supply water	°C	50	60	70	80
Temperature of return water	°C	30	40	50	60
Temperature of sorbent	°C	35	45	55	65
Temperature of regenerator	°C	170	170	170	170
Concentration of sorbent in regenerator	kg of water/kg of mixture	0.45	0.45	0.45	0.45
Concentration of sorbent in absorber	kg of water/kg of mixture	0.55	0.55	0.55	0.55
Dew point after the absorber	°C	8	17	25	34
Moisture content after the absorber	g of water/kg of flue gas	7	12	20	34
Efficiency absorbing system	%	110	109	108	105
Moisture content of flue gases in condensing device	g of water/kg of flue gas	27	48	85	95
Efficiency condensing device	%	108	104	100	99

CLAIMS

1. A method for treating a moist gas stream, wherein:
- in an absorption plant, a recirculating sorbent is loaded with moisture from the moist gas stream;
- in a first heat exchanger, which is connected in a cycle with the absorption plant, heat is absorbed from the recirculating sorbent;
- a part of the moisture-loaded sorbent is supplied to a regeneration plant for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam;
- the regenerated sorbent is recycled to the absorption plant.

2. A method according to claim 1, wherein a heat exchange step is included between the supply of the sorbent to the regeneration step and the recycling of the regenerated sorbent to the absorption plant.

3. A method according to claim 1 or 2, wherein the sorbent is based on liquid absorbents, preferably an aqueous solution of hygroscopic drying agents, more preferably an aqueous solution of lithium halogenides.

4. A method according to claims 1-3, wherein the temperature of the moist gas stream is in the range of from 0 to 500°C.

5. A method for improving the efficiency of a heating boiler, wherein:
- in an absorption plant, a recirculating sorbent is loaded with moisture from flue gases of the heating boiler;
- in a first heat exchanger, which is connected in a cycle with the absorption plant, heat is absorbed from the recirculating sorbent;
- a part of the moisture-loaded sorbent is supplied to a regeneration plant for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam;
- the regenerated sorbent is recycled to the absorption plant; and
- the steam obtained is used for heating, recovering mechanical energy and/or recovering electric energy.

6. A method for improving the efficiency of an air conditioning plant, wherein:
- in an absorption plant, a recirculating sorbent is loaded with moisture from the egressive gas stream of the air conditioning plant;
- in a first heat exchanger, which is connected in a cycle with the absorption plant, heat is absorbed from the recirculating sorbent;
- a part of the moisture-loaded sorbent is supplied to a regeneration plant for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam;
- the regenerated sorbent is recycled to the absorption plant; and
- the steam obtained is used for heating, recovering mechanical energy and/or recovering electric energy.

7. A method for heating a space utilizing a central heating system, comprising a heating boiler, and means for releasing heat to the surroundings, which method comprises:
- in an absorption plant, loading a recirculating sorbent with moisture from flue gases from the heating boiler;
- absorbing heat from the recirculating sorbent in a first heat exchanger, which is connected in a cycle with the absorption plant;
- supplying a part of the moisture-loaded sorbent to a regeneration plant for the sorbent, in which, using heat, the sorbent is regenerated, thereby forming steam;
- recycling the regenerated sorbent to the absorption plant; and
- using the steam obtained for heating, recovering mechanical energy and/or recovering electric energy.

8. An apparatus for recovering heat from a moist gas stream, comprising:
- at least one absorption plant with an inlet and an outlet for the gas stream, means for contacting a liquid sorbent for water with the gas stream, means for discharging the water-loaded sorbent, and means for recirculating the sorbent over the absorption plant;

- a first heat exchanger in combination with said means for recirculating the sorbent;
- a regeneration plant for the sorbent, connected in a cycle with the absorption plant;
- a means for recovering heat and/or mechanical or electric energy, connected with the regeneration plant.

9. An apparatus according to claim 8, wherein the inlet of the absorption plant is connected with the outlet of a preceding combustion plant.

10. An apparatus according to claim 9, wherein the combustion plant is a heating boiler of a central heating system.

11. An apparatus according to claims 8-10, wherein the inlet of the absorption plant is connected with the outlet of a preceding air conditioning plant.

12. An apparatus according to any one of claims 8-11, wherein the temperature of the gas stream in the inlet of the absorption plant is in the range of from 0 to 500°C.

13. An apparatus according to claims 8-12, wherein a heat exchanger is included between the supply of the sorbent to the regeneration step and the return of the regenerated sorbent to the absorption plant.

14. An apparatus according to claims 8-13, wherein one or more parts of the apparatus are integrated into one or more parts of the preceding plant.

15. An apparatus according to claims 8-14, wherein means are included which capture or neutralize contaminants.

16. An apparatus according to claims 8-15, wherein the moist gas stream is generated by a fuel cell.

17. A method according to any one of claims 5-7, wherein the steam is utilized in fuel reforming processes.

18. A method according to claim 1, wherein the steam is converted to water.

19. A method for improving the efficiency of a fuel cell, wherein an apparatus as described in any one of

claims 8-15 is further used for recovering water or steam, while the recovered water or steam is used in a fuel cell.

20. An apparatus according to any one of claims 8-16, wherein the means for recovering energy comprises a fuel reformer and/or a fuel cell.

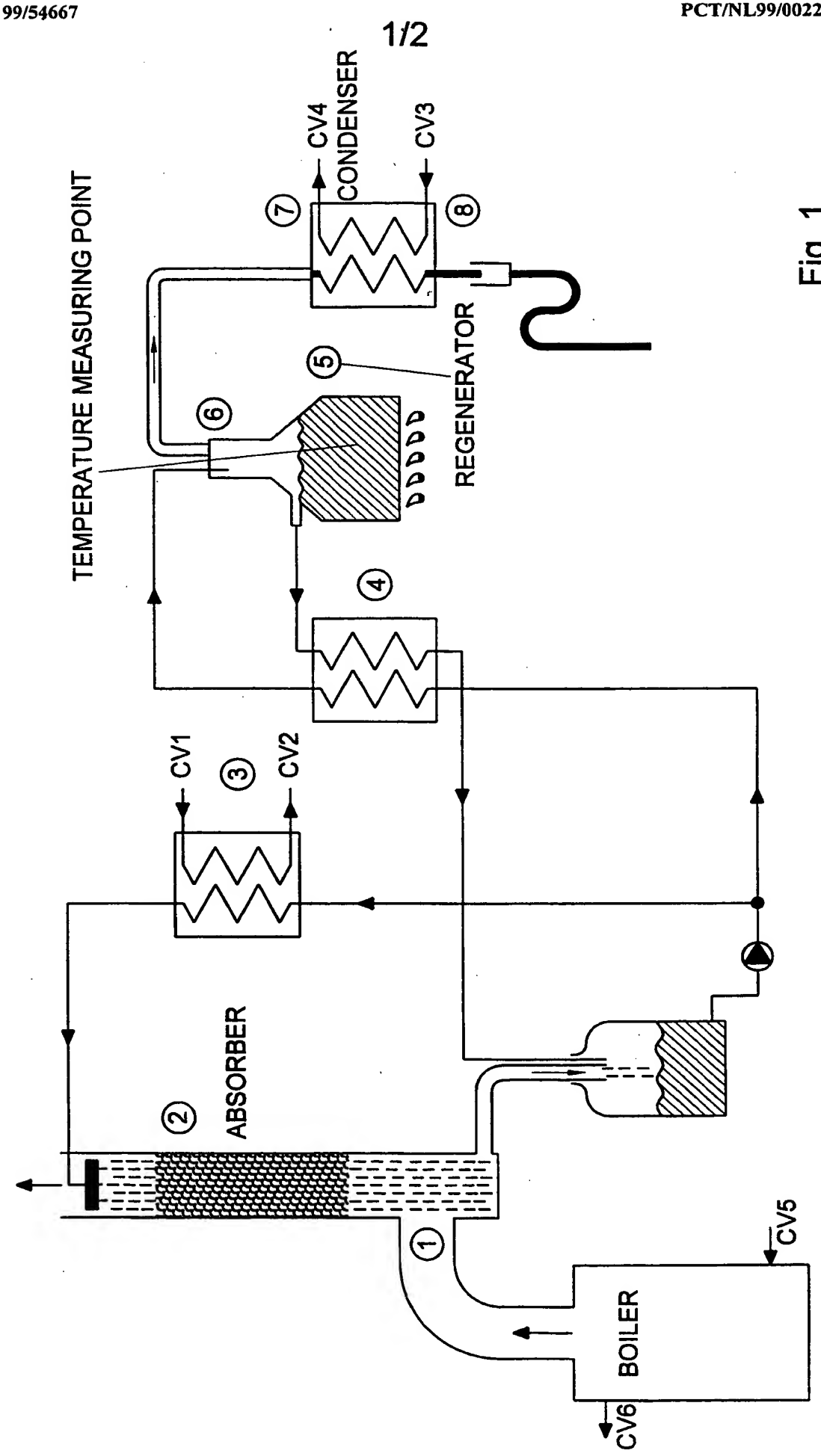
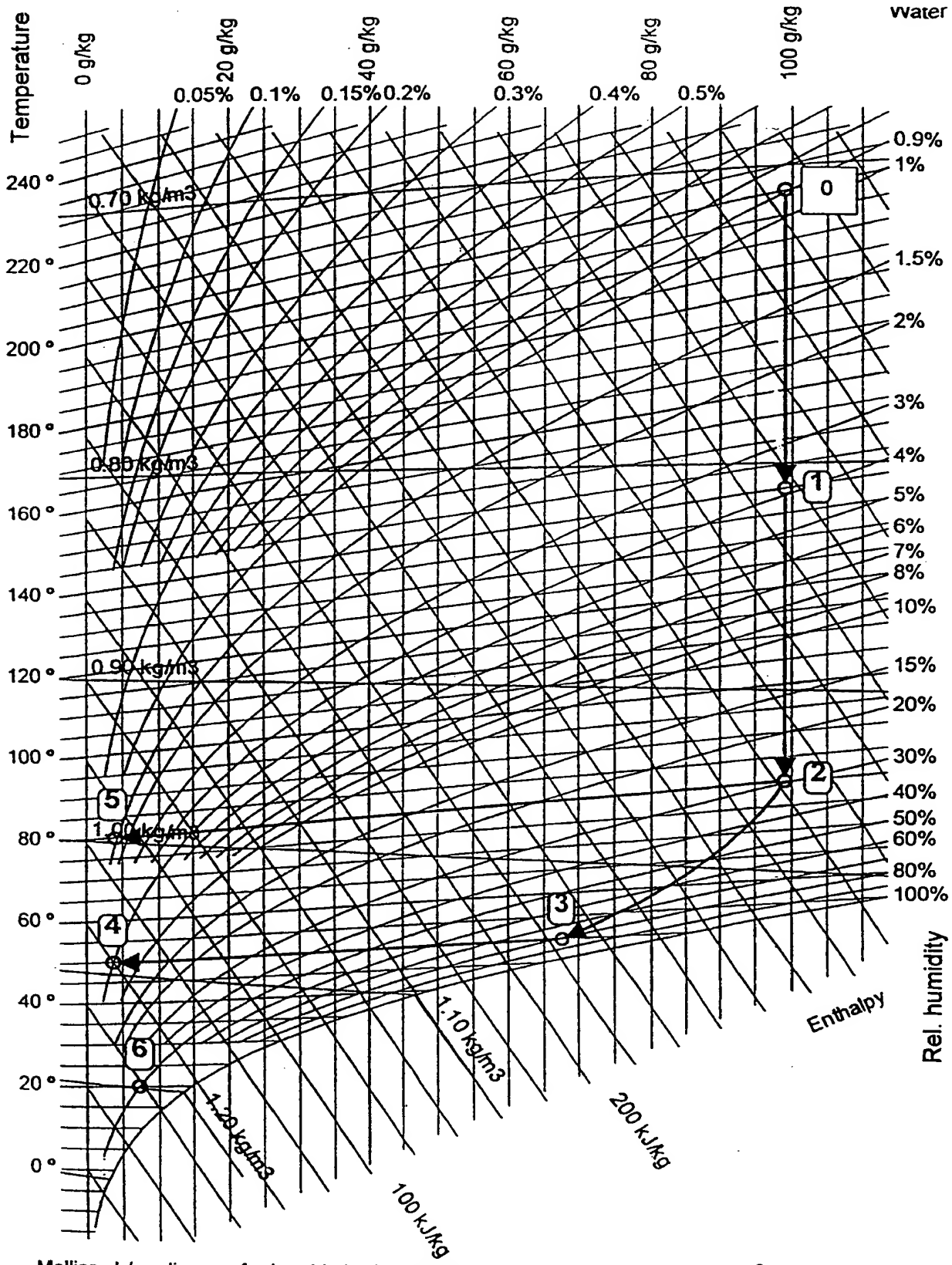

CV4
CONDENSER
CV3
7
8
TEMPERATURE MEASURING POINT
5
REGENERATOR
6
4
CV1
3
CV2
2
ABSORBER
1
CV5
BOILER
CV6

Fig. 1



Mollier - h/x - diagram for humid air - barometric pressure 1.013 bar (0.0000 m / 10.000 °C / 80.000 % RH)

Fig. 2

INTERNATIONAL SEARCH REPORT

Int 'lonal Application No
PCT/NL 99/00229

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 F24F3/14 F24H4/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 B01D F24H F24F F24D H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 860 548 A (RYHAM ROLF) 29 August 1989 (1989-08-29)	1-4,6,8, 11-13,18
A	abstract; figure column 1, line 6 - column 5, line 59 ---	5,7
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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
6 July 1999	06/08/1999

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

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PCT/NL 99/00229

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